

### 3. SALMON IN THE NEARSHORE AND MARINE WATERS OF PUGET SOUND

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*[This section is a draft from late February 2005. This draft does not contain a complete set of references. References are available from Kurt Fresh, NOAA Fisheries, at [kurt.fresh@noaa.gov](mailto:kurt.fresh@noaa.gov) or (206) 860-6793]*

#### **A) Introduction.**

In this chapter, we present the salmon portion of our salmon recovery conceptual model (Figure xx). This “salmon piece” presents our “hypotheses” about how salmon use the nearshore and offshore ecosystems of Puget Sound and how use of habitats in these ecosystems affects populations and ESUs. The conceptual model proposes that ecosystem processes (e.g., sediment movements and food web) as controlled by certain factors (e.g., geology and climate) define habitat conditions. Salmon then interact with and respond to this habitat. Recovery strategies and actions are then targeted primarily at the processes that create and maintain habitat.

Our discussion focuses primarily on salmon in nearshore ecosystems because: 1) we know more about nearshore use than we do offshore habitat use, and 2) the nearshore ecosystems of Puget Sound are where salmon and people most closely interact. Because the ultimate intent of this chapter is to help identify recovery strategies and actions at the subbasin scale, we also consider differences in use between subbasins when such distinctions can be made. We will highlight key uncertainties about salmon in the nearshore that will be considered further in the adaptive management plan (Chapter xx). We focus on Chinook salmon and summer chum salmon because of their protected status under ESA. Bull trout are only briefly discussed in this chapter. The USFWS completed a separate recovery plan for bull trout that is available at the USFWS website <http://pacific.fws.gov/bulltrout/jcs/index.html>.

The chapter consists of the following major section:

1. An introduction to the listed populations of Chinook and chum salmon within Puget Sound.
2. Effects of species, population, and life history strategy on use of nearshore habitats.
3. Nearshore habitat conditions.
4. A description of how Chinook salmon and summer chum salmon use nearshore and offshore habitats.
5. Differences between sub-basins in salmon use of Puget Sound.
6. Response of individual salmon, populations, and ESUs to habitat in Puget Sound. .

#### **b) The Puget Sound Chinook Salmon and Summer Chum Salmon ESUs**

Chinook Salmon.

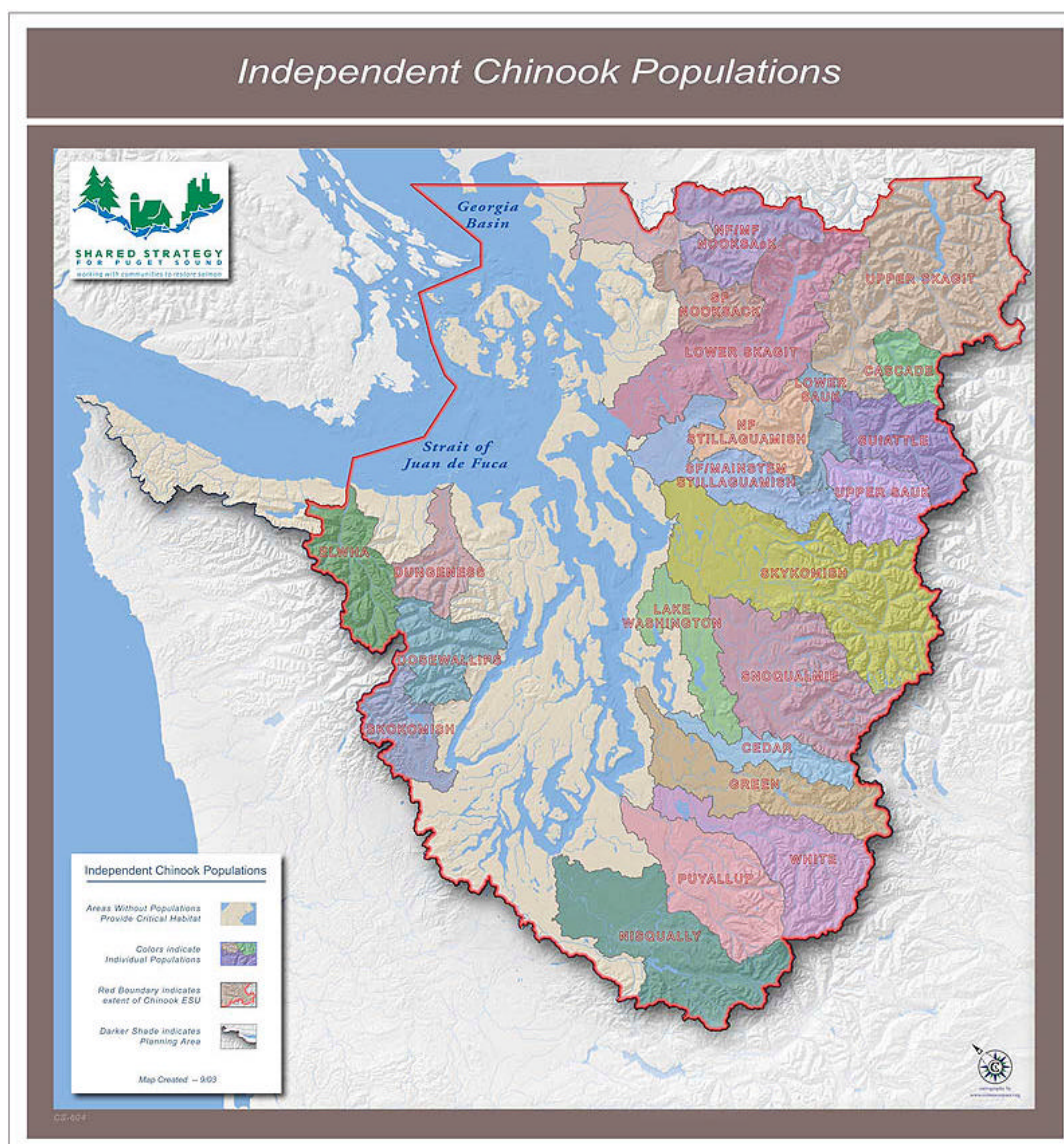
The Puget Sound Chinook salmon ESU contains 22 independent populations (Table xx). The geographic distribution of the 22 Chinook salmon populations is presented in Figure xx. These populations spawn primarily in the 13 largest watersheds entering Puget Sound including the large systems flowing west from the Cascades into Puget Sound. Chinook salmon are also occasionally reported to spawn in smaller tributaries in places like South Puget Sound.

Myers et al. (1998) reported Chinook salmon within the Puget Sound ESU are primarily ocean type fish. Since first used by Gilbert (1913), the terms ocean type and its converse, stream type, have been widely applied to describe salmon species and populations (e.g., Healey 1991). We use the terms stream and ocean type consistent with Myers et al. (1998) to separate Chinook salmon populations into two groups based upon certain characteristics exhibited by juveniles during their first year of life. These characteristics include how long they rear in freshwater, when they emigrate from freshwater and how long they spend in estuarine habitats. Populations are referred to as ocean type if most of the members of the population migrate to sea early in their first year of life after spending only a short period (or no time) rearing in freshwater. A shorter period of freshwater rearing is usually correlated with more extensive use of estuarine and oceanic habitats. In contrast, most members of stream type populations rear for at least a year in freshwater and so spend comparatively less time in estuarine and ocean habitats.

Most of the ocean-type Chinook spawning in Puget Sound enter freshwater to spawn in late summer or fall (Healey 1991); these fall spawners are referred to 'fall run' Chinook salmon. There are also spring and summer Chinook salmon (entering freshwater in the spring and summer, respectively, but still spawning in the fall) spawning runs within the Puget Sound ESU. We refer the reader to the NOAA- Fisheries Chinook Salmon Status Review website (<http://www.nwfsc.noaa.gov/publications/techmemos/tm35/index.htm>) for a comprehensive discussion of juvenile Chinook life history and ecology.

**Table 2.** Independent populations of Puget Sound ESU Chinook salmon

1. Elwha	12. Skykomish
2. Dungeness	13. SF/Mainstem Stillaguamish
3. Dosewallips	14. Upper Sauk
4. Skokomish	15. Lower Sauk
5. Nisqually	16. Suiattle
6. Puyallup	17. NF Stillaguamish
7. White	18. Cascade
8. Green	19. Upper Skagit
9. Cedar	20. Lower Skagit
10. Snoqualmie	21. SF Nooksak
11. Lake Washington	22. NF/MF Nooksak



**Figure 3.** Independent populations of Puget Sound Chinook salmon.

### Summer Chum Salmon.

Within Puget Sound, chum salmon can be divided into three types of populations based upon spawning timing. Although there is some overlap between the three groups, summer-run chum salmon spawn primarily in August and September, normal or fall-run chum spawn from October to December and late-run chum spawn from January to March. Most of the chum salmon spawning in Puget Sound are part of fall-run populations. **Nine** populations of summer chum salmon found in the Hood Canal and eastern Strait of Juan de Fuca have been grouped into what is referred to as the Hood Canal summer chum ESU Table 3, Figure 5); these nine populations have been listed as threatened. There are other summer chum populations in Puget Sound (south Puget Sound) that have not been listed. We refer the reader to the NOAA- Fisheries Chum

Salmon Status Review website

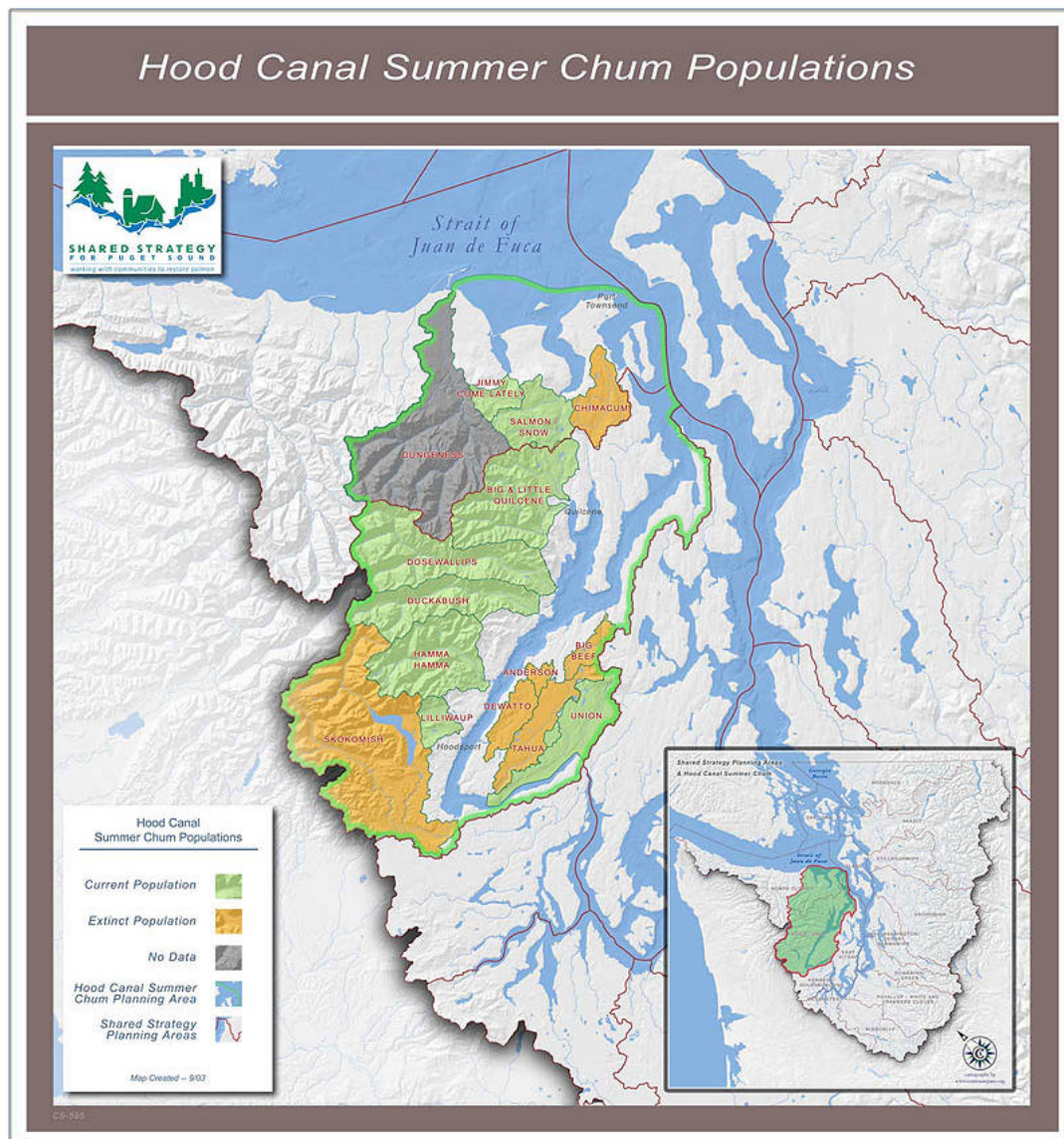
(<http://www.nwfsc.noaa.gov/publications/techmemos/tm32/index.html>) for a comprehensive discussion of chum salmon demographic, general life history and ecology.

This chapter addresses the eight independent populations collectively, not separately. The Hood Canal Coordinating Council (HCCC) is completing one chapter specifically addressing Hood Canal summer chum salmon within Hood Canal.

**Table 3.** Independent populations of Hood Canal summer chum salmon

1. Jimmy Comelately	5. Duckabush
2. Salmon/Snow	6. Hamma Hamma
3. Big and Little Quilcene	7. Lilliwaup
4. Dosewallips	8. Union





**Figure 5.** Independent populations of Hood Canal summer chum salmon.

### **c) Influence of Species, Population, and Life History Strategy on Nearshore Habitat Use.**

It is clear from our 50+ years of research on salmon in nearshore systems throughout the Pacific Northwest that we cannot define a generic, one size fits all model of salmon use of the nearshore. Rather, we have found that differences in use of nearshore habitats occurs between species, between populations within a species, and between individuals within a population (e.g., Fresh et al. 1979; Levy and Northcote 1981; Levy and Northcote 1982; Healey 1982; Simenstad et al. 1982). These differences must be accounted for in planning, implementing, and monitoring protection and restoration strategies and actions for salmon in the nearshore. For example, actions that target

specific habitats or landscapes to benefit one species or population may not be as beneficial to other species and populations.

Species-specific differences in use of nearshore habitats have long been appreciated. For example, the most estuarine dependent species in the juvenile stage is Chinook salmon (Healey 1982) because they spend the most time rearing and feeding in these habitats; chum salmon are considered to be the second most dependent upon nearshore habitats (Healey 1982; Simenstad et al. 1982). Recently, we have begun to appreciate that population of origin and characteristics of individuals within a population can have a significant effect on use of nearshore habitats which can be important in the design, planning and implementation of recovery strategies and actions. Here, we briefly discuss the importance of population and sub-population differences in use of nearshore habitats.

### Population

Populations are geographically discrete, self perpetuating, and semi isolated (in terms of genetic exchange) reproductive or breeding units of salmon; they are the fundamental unit around which much of modern salmon research and management is organized. McElhany et al. (2000) defines a population as “any collection of one or more local breeding units whose population dynamics or extinction risk over a 100-year time period is not substantially altered by exchanges of individuals with other populations.” The extinction of one independent population would have negligible impact on the 100-year extinction risk of other independent populations (McElhany et al., 2000).

Populations form as a result of the specific spawning and rearing conditions (e.g., hydrological, estuary morphology, climate, ocean environment) experienced by different groups of salmon. Over long time scales, groups of salmon adapt to the specific habitat conditions that they encounter. These adaptations are expressed by each population in how they use the habitats available to them (e.g., residence time, body size, age at return, timing of life history events, etc). Therefore, each population within the Chinook salmon and summer chums salmon ESUs do not use habitats (including nearshore habitats) in the same way. There is a wide body of literature that demonstrates that habitat use depends upon population of origin (Carl and Healey , Wilmot and Burger 1985, Burger et al. 1985, Beachum and Murray 1987, Burgner 1991, Healey 1991, Wood 1995, Woody et al. 2000, Hodgson and Quinn 2002, Miller and Sadro 2003, Ramstad et al 2003).

The local adaptations by populations to spawning and rearing conditions results in genetic differences between populations, although some differences may result due to genetic drift (Stearns 1992). Within the Puget Sound ESU, the 22 populations of Chinook salmon are genetically distinct from each other and from other populations outside the ESU. It is unknown whether genetic differences exist within the Hood Canal/Straits summer chum ESU.

### Life History Strategy

Within any population, individuals vary in their approach to using spawning, rearing, and migration habitats in space and time. Differences within populations in use of nearshore habitats in such attributes as residence time, timing of arrival in the estuary, habitat usage, and size of arrival in the estuary has been demonstrated by a considerable number of studies (Reimers 1973, Carl and Healey 1984, Levings et al. 1986, Quinn and Unwin 1993, Bottom et al. 2001, Miller and Sadro 2003, D. Bottom, NOAA Fisheries, personal communication).

Each alternative approach to the spatial and temporal use of spawning, rearing, and migration habitats by individuals within a population can be defined as a life history strategy or life history trajectory (we use these terms to refer to the same thing) (Wissmar and Simenstad 1998). In the extreme, each member of a population is unique and has its own trajectory or life history strategy. However, individual trajectories can be bundled or aggregated into a more limited number of general trajectories based upon definable patterns in their spatial and temporal use of habitats (Reimers 1973, Carl and Healey 1984, E. Beamer, SSC, personal communication). In general, the abundance of members associated with each strategy will vary between and within populations in response to a wide range of factors operating over multiple scales of space and time. Under the prevailing environmental conditions, some strategies will produce more adult spawners than other strategies. As conditions change, the distribution or proportion of members associated with each life history strategy can then shift. Over short time scales (e.g., annually), the distribution of members associated with each strategy can vary in response to annual variability in flow, water temperature, biological interactions such as predation, and the occurrence of El Nino events. A sustained shift in conditions (e.g., a climate shift, anthropogenic influences) can potentially produce more significant shifts in the distribution of life history traits (Hilborn et al. 2003).

There is not a single or correct way to define life history strategies within a population. In this chapter, we consider four alternative life history strategies for juvenile Chinook salmon use of nearshore habitats based primarily upon research by Eric Beamer of the Skagit System Tribe. The primary attributes we use to distinguish these four life history strategies are with respect to how they use delta habitats, especially the size at estuarine entry and arrival time in the estuary. Size at entrance into the estuary can be used to classify life history strategy because there is a linkage between fish size and habitat use (Healey 1980, 1982; Levy and Northcote 1981, 1982; Simenstad et al. 1982; Levings et al. 1986; Miller and Sadro 2003). For example, time spent in the estuary generally decreases as the size of the fish entering the estuary increases. The time the fish arrive in the estuary also varies within a population in a reasonably predictable way (Carl and Healey 1984; Bottom et al. 2001). Because habitat conditions vary throughout the year, arrival timing represents a reasonable way to describe habitat use by salmon. Fish from any one population can arrive in the estuary during most months of the year (e.g., Rowse and Fresh ) and there is a general relationship between arrival timing and fish size. Size at arrival in the estuary generally increases with Julian day of estuarine entry.

The following are the four life history strategies used in this chapter for Chinook salmon populations:

1. **Fry migrants** – this life history type spends little time in freshwater after hatching (between 1 -10 days) and migrates rapidly through its natal estuary/delta. These fish rear in and along nearshore regions, particularly in non-natal estuaries (what are referred to as pocket estuaries) that may be relatively remote from their natal river. Fish are small (<50mm) at the time of estuarine entry,
2. **Delta fry** - similar to pocket estuary fry except delta fry may remain in natal delta habitats to rear for extended periods of time. This life history type is also small sized (<50mm) when entering an estuary, and will leave their natal estuary at a size of about 70mm,
3. **Parr migrants** - remain in freshwater and rear for up to 6 months before migrating to the estuary. Fish from this life history type are larger in size when entering an estuary,
4. **Yearlings** - rear in freshwater for approximately one year before migrating to Puget Sound. Fish from this life history type spend a short time in an estuary.

A full accounting of these life history strategies associated with all Chinook salmon populations in Puget Sound has not yet been conducted. However, our hypothesis is that all four life history strategies exist in each population, although the mix of these strategies undoubtedly varies between populations. We believe this is a plausible hypothesis for several reasons. First, where detailed studies of estuarine use by juvenile Chinook salmon in Puget Sound have been conducted, data suggests that all four life history strategies exist in each natal estuary (Table xx). Second, research in systems outside the ESU indicates similar types of life history strategies can be defined based upon use of natal estuarine habitats (e.g., Carl and Healey 1984). For example, Fresh et al. (in press) proposed a similar hypothesis in the Columbia River that each population regardless of origin exhibited multiple life history approaches to use of the Columbia River Estuary. Emerging data from ongoing research in the Columbia River estuary has supported this hypothesis (xxxxxxxxxx).

Alterations of delta habitats has probably affected the expression of the delta fry life history strategy in some systems; the habitat simply is not there for the fish to use. Historic changes in natal watersheds may have completely altered the mix of life history strategies including creating strategies that did not historically exist. In some systems where fry have been found, separating them into the delta and migrant types is challenging unless sampling can be extended outside natal systems to find the migrant fry type. Otolith analyses could help make such distinctions as well. In watersheds that have multiple populations (e.g., the Snohomish River), we have been unable to determine population specific life history strategies; we are only able to identify the existence of life history strategies at a watershed scale.

In general, once juvenile Chinook salmon exit natal deltas, we are unable to distinguish the different life history strategies and so we do not know if differences in habitat use persist. One exception is use of a rare habitat type in nearshore areas by migrant fry. As a result, once the Chinook salmon exit natal deltas, we will aggregate the four life history strategies into a single generic Chinook salmon model. This is not to say that there are not life history strategies in



Puget Sound. In fact, some Chinook salmon within a population appear to reside in Puget Sound for extended periods while most members of a population migrate to the ocean. These resident salmon are often referred to as blackmouth. We do not know how juvenile life history in the delta may be related to extended residency in Puget Sound- e.g., do residents come from certain populations or certain delta life history strategies. Where appropriate, we will consider other life history strategies during residence in Puget Sound.

Although our treatment of life history strategy is based upon use of Puget Sound, there may be other expressions of life history diversity by Chinook salmon populations. For example, spawning location (headwater versus mainstem spawning) within a watershed may be an important element of life history diversity. Similarly, spawning by some Chinook salmon in small, independent tributaries may represent an element of diversity.

Although summer chum may have some consistent life history strategies within their populations, we have yet to identify this type of diversity within the Hood Canal ESU. As a result, we do not distinguish alternate life history approaches in our consideration of summer chum use of nearshore habitats in this chapter.

#### **d) Nearshore Habitats**

The nearshore ecosystems of Puget Sound consist of a mix of habitats that juvenile salmon can potentially occupy. Habitat is the physical, biological, and chemical characteristics of a specific unit of the environment occupied by a specific plant or animal (in this case, salmon). Thus, habitat is unique to specific organisms and encompasses all the physiochemical and biological requirements of that organism within a spatial unit.

##### **Physical, Chemical, and Biological Salmon Habitat**

A diverse array of attributes can be defined to define physical, biological, and chemical habitat of salmon in nearshore ecosystems. Physical habitat represents the structural features of the habitat used by salmon. Within a delta, physical habitat includes such attributes as location of a marsh channel, length of the channel, average depth, connectivity to main distributary channel, depth profile, and so on. Within a shoreline environment, physical habitat includes substrate composition, beach gradient, exposure to wave energy, characteristics of adjoining riparian vegetation, and composition of habitat along the beach. The most obvious chemical habitat attributes are temperature, salinity and dissolved oxygen. These three parameters have a significant affect on the functions of that habitat. For example, water temperature affects metabolic rates and hence food acquisition and growth. Salinity regimes within a delta can determine the physiological changes fish undergo as they undergo smoltification.

Biological habitat includes all the plant and animal species and communities that salmon interact with. Salmon can interact both directly and indirectly with biota. For example, direct interactions are those where salmon prey on a species, compete with a species for resources, or are preyed on by a species. Indirect interactions with biota include those occurring with attached vegetation such as eelgrass and marsh plants.

These plants can produce prey or provide refuge from predation but they are not directly used (eg eaten) by salmon. Biological habitat components can vary according to their location in the nearshore, time of year, size of the salmon, species of salmon being considered, and so on.

The interaction of salmon with their predators and prey can be organized into food webs. These food webs illustrate the interrelationships of salmon with other members of the nearshore ecosystems and clearly show that factors affecting the production of particular species can significantly affect salmon performance. For example, Figure xx shows a portion of a non-deltaic nearshore food web that includes salmon. At the life stage represented in this Figure, salmon are larger and exploit herring and other baitfishes as food. Thus, the ecosystems processes that affect production of herring and these baitfishes (e.g., habitat used by herring, sources of organic matter used by prey of herring, other predators of herring, and so on) can have a direct affect on growth rates and ultimately survival of salmon. Similarly, salmon of this size in this habitat are preyed on by marine mammals and birds. Factors affecting population sizes of these species can directly affect salmon survival.

Within both delta and shoreline habitats, chironomids and other insects are important food items. These insects can come from either aquatic or terrestrial habitats depending upon the type of insect they are. For example, some chironomids originate from within marshes. Their productivity then depends upon a variety of habitat factors that affect chironomids such as their food supply and the organic matter important to the production of insect food and physical habitat that the insect occupy (e.g., plant species).

### Salmon Habitat: Effect of Scale

The biophysical and chemical attributes of habitat can be measured at multiple scales of space and time. These range from the “microscopic” (mm to cm) to the regional (hundreds of square km). Traditionally, juvenile salmon habitat in nearshore ecosystems has been considered primarily at a site or patch scale. Examples of patch or site scale habitat attributes in a tidal marsh include area of the marsh, volume of the marsh, vegetation type and density, salinity and temperature patterns, and channel depth at the mouth of blind tidal channels. However, it has become increasingly apparent in recent years that simply relying on site scale habitat attributes to study, manage, protect and restore salmonid populations can lead to approaches that are ineffectual. Instead, as Simenstad (2000), Simenstad et al. (2000) and others have proposed, we believe that a landscape view of habitat is also essential. Landscape context of habitat refers to the spatial arrangement of habitat, including its size and shape; location of the habitat within the estuary; the composition of surrounding habitat; and connectivity with other habitats (Turner 1989). A landscape view of salmon habitat integrates specific sites and habitat types with all other elements of the landscape, including the arrangement, size, shape, location, connectivity to other habitats, and accessibility of that habitat to resources. In short, what this means is that the function of any unit of habitat depends upon the context of that habitat within the “bigger picture.”

A landscape approach to salmon habitat is warranted for several reasons. First, the physiological and ecological requirements of the fish are rapidly changing as they move through the nearshore implying a need to change habitats (Simenstad et al. 2000). Second, during their residence in the nearshore, salmon juveniles are mobile and migratory and so are not affiliated with a particular site for very long. In essence, juvenile salmon are always going someplace and have always come from someplace. Third, nearshore habitats are dynamic in nature; depth, temperature, salinity, turbidity levels, and many other attributes continuously and rapidly change of multiple spatial and temporal scales. Many habitats such as shallow water, blind channels are not consistently accessible. The ebb and flood of the tide in delta marshes means that fish are being redistributed every tidal cycle because of changes in depth. Finally, many of the process that create and maintain habitat operate at large spatial scales (see following section).

Principles and concepts of landscape ecosystem are relatively recent and can be found in such sources as Turner (1989); they are being applied in restoration of salmonid habitats in freshwater (Roni et al. 2002). One example of the application of landscape metrics in nearshore systems is from the Chehalis River where Hood (2002) showed how differences in landscape features (e.g., perimeter and surface area) of a restored and natural channel affected their function. In addition, Simenstad (2000) discussed juvenile salmon integration at large landscape scales in his assessment of the Commencement Bay aquatic ecosystem. He described three landscape elements important to salmon and salmon recovery in an estuarine landscape: 1) *patches* ("non-linear surface areas, relatively homogeneous internally...that differ in appearance from surrounding matrix in which they are imbedded," characterized by several variables and determined by a combination of several processes; can be referred to as habitats), 2) *matrix* ("surrounding area that has a different composition or structure from embedded patches; the most extensive, connected element in the landscape") and 3) *corridors* ("narrow strip of land (or water) that differs from the matrix on either side;...can also be considered a narrow and often long patch that provides a connection between two or more similar patches").

As our understanding of landscape features and habitat functions for salmon increases in nearshore areas, the recommendations of Simenstad et al. (2000) provide useful initial guidance for incorporating landscape concepts in the recovery of nearshore ecosystems:

1. Use natural landscape templates as templates to increase our understanding of landscape attributes. Use templates that are specific to the estuary and local region to guide restoration,
2. Emphasize corridors and linkages (i.e., connectivity) between habitats at all scales (e.g., between and within complexes of habitats such as in marsh habitats,
3. Incorporate landscape elements that maintains a natural diversity of sources of organic material, and
4. Promote landscape structure that accommodates fish responses to climate and natural disturbance regimes

### Attributes of Salmon Habitat: Opportunity and Capacity

Simenstad (2000) and Simenstad and Cordell (2000) proposed that salmon habitat attributes at any scale could be considered from two primary perspectives. First, there are attributes of habitat that relate to the *quality* or *capacity* refers to habitat attributes that encourages production for juvenile salmon via things such as feeding and growth and reduced mortality. Examples include prey production and availability and maintenance of prey communities. The second category is *opportunity*, which refers to the juvenile salmon's ability to "access and benefit from the habitat's capacity." Examples include tidal elevation, important during tidal flooding, available geomorphic features "that often dictate both the extent of fish access into habitats and the interface along which they feed," refugia from predation via physical features, and "proximity to deepwater habitats."

The measure of the usefulness or value of any unit of habitat to salmon is a product of the combined effects of the capacity of the habitat to support salmon and the opportunity the fish have to use that habitat. There are a number of physiological and behavioral measures of how well that habitat functions for salmon including growth rates, residence time, migration rate, distributional patterns, relative abundance, physiological responses, and morphological changes.

The ultimate measure of the value of habitat to salmon is how well fish occupation of that habitat promotes survival. Measuring survival of any cohort for any species during nearshore residence is difficult so has been rarely accomplished. Bax (1983) and Parker (1968) provide estimates of early marine mortality of chum and pink juvenile respectively. Estimates between the two studies vary by about one order of magnitude and suggest that mortality is high and variable. On the Columbia River, Ryan et al. (2003) found that predation rates on PIT tagged smolts in the Columbia River by nesting birds in the estuary varied by species and size. For example, loss of PIT tagged steelhead was about 18% while about 2% of smaller Chinook were lost. Given that these are only PIT tagged fish mortality estimates, levels would be higher if the untagged portion of the population was included. Recent advances in technology such as PIT tags and small sonic transmitters may make mortality estimates more logistically feasible.

The ability of any unit of habitat to promote or affect survival reflects the net cumulative ability of all the attributes associated with that habitat (those related to both capacity and opportunity) to support four main functions: 1) foraging and growth, 2) avoidance of predators, 3) the physiological transition from freshwater to saltwater, and 4) the ability of the fish to migrate to ocean feeding habitats (Simenstad et al. 1982; Simenstad and Cordell 2000). Although we discuss these four functions in greater detail below, they are clearly interrelated. For example, growth and survival are interrelated as growth rate reflects how rapidly the fish can "outgrow" portions of their predator population. Similarly, fish that "struggle" to make the transition to saltwater may be less able to avoid predators than those that make a smooth transition.

Feeding. Juvenile salmon feed and grow in all habitats that they occupy. Not surprisingly, the types of prey available to the juvenile Chinook salmon will vary widely across the habitats occupied by salmon. For example, pelagic copepods are an abundant prey along shorelines but relatively rare within deltas. There is not a correct prey type for juvenile Chinook salmon. Instead, fish appear to feed somewhat opportunistically as a function of habitat occupied, time of year, and fish size. It is not known if fish of different life history strategies occupying the same habitat have differences in diet due to their life history strategy. Often, there is considerable individual variation in diet for fish of similar size captured in the same habitat type at the same time of year.

In general, juvenile Chinook salmon eat a diverse array of prey items that originate from terrestrial, aquatic, benthic and water column sources. For several of these prey types, the food web producing this prey is fueled by organic matter originating from within the nearshore. Such nearshore food webs based upon detritus appear to be especially important to the smaller size classes of juvenile Chinook which eat these types of prey. Several general patterns emerge from a comprehensive analysis of juvenile Chinook salmon diets. First, as fish size increase, prey size increases as well (Simenstad et al. 1982; MacDonald et al. 1987). Second, in all landscape classes, insects, especially chironomids are important prey (Simenstad et al. 1982; Shreffler et al. 1992; Miller and Simenstad 1997; Gray et al. 2002, MacDonald et al. 1987; Healey 1991).

There are relatively few estimates of growth rates of juvenile Chinook salmon and most of what is known comes from estuary/delta habitats. Considerable variability exists both within and between deltas but growth rates during nearshore residence appear to be some of the highest exhibited by the fish during their life histories. For example, growth rates in different systems ranged from a high of 3.0 mm/d in the Sixes River to 0.27 mm/d in another study of the Sixes River (see Miller and Simenstad 1997, Table 2). Within any one system, growth can vary considerably as illustrated by the threefold difference Reimers (1973) found for juvenile Chinook in the Sixes River. Again, we do not know what factors account for these differences.

Studies in the Skagit River delta suggest that food can be limiting in nearshore areas under some conditions. Beamer has found that the carrying capacity of estuarine habitats in this system are often exceeded under current conditions (E. Beamer, SSC, personal communication to K. Fresh, NOAA-Fisheries). Beamer observed that there was a relationship between the number of fry migrants entering the estuary and the density of fry in tidal channels. While this relationship suggests a carrying capacity, it is not clear what happens to the fish as a result- e.g., do they leave and move to another habitat such as shoreline areas, is their growth rate affected, is survival affected. Given that the Skagit Delta arguably is the best estuarine habitat in Puget Sound and there have been extensive losses of habitat in other deltas, it is not unreasonable to assume delta habitats in other systems are now often at or exceeding their carrying capacities for Chinook fry as well.

Refuge From Predation. During their life history, salmon are subjected to predation from a wide variety of fish, birds, and mammals (Fresh 1997). Simenstad et



al. (1982) suggested the nearshore could provide a refuge from some of this predation. There are a number of mechanisms by which this could occur. First, estuary/delta habitats are often turbid as a result of sediment laden river water and resuspension tidally of fine materials from delta habitats. Several studies have found that some turbidity can reduce visibility of salmon juveniles to predators while high enough levels of turbidity can limit the ability of juvenile salmon to forage for food (Gregory). Two, the shallow water habitats associated with many shoreline areas, pocket estuaries, and deltas can provide a refuge from some larger piscivores such as cutthroat trout and large sculpin. Third, high growth rates can provide a refuge from predators by allowing the juvenile salmon to outgrow their predators.

Physiological transition. Juvenile salmon undergo a physiological transformation during their transition from freshwater adapted to saltwater adapted animal. Part of this transformation occurs in the nearshore. Despite a large amount of research on smoltification (e.g., Wedemeyer et al. 1980), we have a limited understanding of the physiological changes juvenile Chinook of any size are undergoing as they pass through estuaries and how habitat affects physiological condition. It is possible that habitat selection for at least part of life in nearshore habitats is dictated by physiological needs so that water chemistry, particularly salinity, may play a more critical role in defining fish behavior in estuaries than other habitat attributes. Presumably, because the salinity patterns are most diverse and different in estuary/delta habitats, it seems reasonable to hypothesis these habitats are most critical for the physiological transition of the fish. Chinook salmon fry can tolerate some salinity but most fry are found in lower salinity habitats such as marsh channels (Grette *et al.* 2000). Some Chinook fry may remain in lower salinity or freshwater regions for extended periods after arriving at an estuary (Grette *et al.* 2000). In addition, estuaries may benefit juvenile salmonids such as Chinook and chum salmon because these regions can offer a gradual transition from a freshwater environment to a saltwater environment (Aitken 1998).

Migratory pathway. Salmon are a migratory animal over their entire life history so it is important to recognize that salmon are always going someplace and coming from someplace else. Thus, all habitat that is part of the life history of salmon is a part of the pathway they must follow. To survive, salmon depend upon being able to move between habitats. The nearshore represents the part of the salmon pathway from freshwater spawning and rearing areas to oceanic feeding grounds. Thus, the connectivity and integrity of nearshore habitats as a whole will have a profound affect upon the ability of salmon to make this journey to ocean feeding habitats. Simenstad (2000) suggested that salmon recovery should emphasize corridors and linkages (i.e., connectivity) between habitats at all scales (e.g., between and within complexes of habitats such as in marsh habitats). Certain landscapes and habitats will likely be more important to different species and life history strategies within species. Therefore, because multiple species and life history strategies are occupying this pathway simultaneously, a diversity of habitats and the connectivity of this habitat seems especially important to its functions as a migratory corridor.

### **e) Use of Nearshore Habitats by Salmon**

In the following section, we present general descriptions of how salmon use nearshore habitats. Our objective here is to develop some general rules or principles of habitat use that can be applied in developing salmon recovery strategies and actions. In a subsequent section, we identify some important. We discuss summer chum salmon and Chinook salmon separately. Because we cannot yet differentiate different life history strategies for summer chum salmon, we present a generic summer chum salmon model, relying primarily upon information provided in Salo (1991) and the summer chum conservation plan (XXXX). For Chinook salmon, we discuss delta habitat use based upon the four life history strategies defined previously. Once fish exit natal deltas, however, we aggregate these four life history strategies into a general Chinook salmon model and only consider different life history strategies when consistent with available information. .

In order to discuss use of nearshore habitats, a method of describing nearshore habitats is needed that is consistent with information on habitat use by salmon and the landscape classes being used to analyze each sub-basin. Although a number of habitat classifications are available, these are too detailed compared to our knowledge of salmon use. Therefore, to describe use of Puget Sound ecosystems by salmon we will consider the following habitat types:

1. Natal estuary- Fluvial processes tend to dominate, such as delivering sediments. For Chinook salmon, this includes the larger systems throughout Puget Sound. Summer chum natal estuaries are smaller and limited to the Hood Canal and Straits.
2. Other estuary- Fluvial processes tend to dominate, such as delivering sediments.
3. Bays/Shallow Water, Low Velocities- Tidal processes are especially important to sediment delivery and movement. Pocket estuaries are defined as types of bays (other names used include barrier estuaries and barrier lagoons) that are distinguished by being geomorphically constricted at the mouth by a barrier. The amount of freshwater influence can vary.
4. Beaches- Wave dominated systems.
5. Water column associated with the shore- Water column extending from a depth of about 5m to 20 m (lower limit of the photic zone).
6. Puget Sound offshore- Surface to bottom from a depth of 20m.

#### **Chinook Salmon.**

One of the major variables affecting use of nearshore habitats is when the fish initially enter the natal delta. Within the Puget Sound Chinook salmon ESU, spawning occurs in the fall. Based upon arrival of fish in the estuary in December (E. Beamer, personal communication), emergence begins as early as late December and continues through April. The pattern of emergence (e.g., timing) depends primarily upon population, where spawning occurred (e.g., head water stream versus a lower mainstem stream), when the eggs were deposited, oxygen levels, and water temperature. Water temperature has a critical influence on variability in emergence timing with warmer water temperatures speeding up development and resulting in earlier emergence timing.

Emerging fry embark on one of three major pathways. First, they can begin migrating downstream soon after emergence and enter the estuary with little or no rearing. Second, emerging fry can rear for less than year in freshwater for migrating downstream to enter the delta; these are parr migrants. Third, they can rear for over a year and emigrate as yearlings. While we can distinguish use of natal estuaries by different life history strategies, our ability to discriminate use in Puget Sound is limited. As a result, we consider first use of natal estuary habitat by each strategy and then aggregate them to discuss habitat use in Puget Sound. Each of these strategies is considered below.

Fry. Fry begin entering natal deltas in at least mid-December (Beamer personal communication) and continue until at least April. Healey (1980) suggested that abundance of fry migrants peaked in April and May in the estuary and that the fry disappeared from the delta prior to the arrival of fingerling migrants. The peak of fry in the Snohomish River delta also occurred in approximately April and May (M. Rowse, NWFSC, personal communication) while Levings et al. (1986) reported a similar peak in abundance in the estuarine habitats of the Campbell River estuary. Although size at estuarine entry can be variable, fry are less than 50mm when they enter the estuary (Levy and Northcote 1982; Beamer et al. 1993; M. Rowse NWFSC, personal communication; E. Beamer SST personal communication).

As the Chinook salmon fry enter their natal estuary, they can either quickly pass through their natal estuary into Puget Sound or they can remain in their natal estuary to rear for extended periods before exiting. The fry that pass through natal deltas without rearing are the migrant fry strategy. At present, we lack knowledge of how they disperse throughout the nearshore after exiting the estuary. We hypothesize physical processes associated with river and receiving environment primarily determine dispersal. One possible mechanism that might control dispersion is patterns of freshwater outflow and the oceanography of the area adjacent to the delta. The migrant fry may entrain in the brackish water of the natal system plume and move with this plume.

Dispersal requires further study and is important because it will help define which shoreline areas are critical to this life history strategy. Until we conduct these studies on dispersal, we assume that shoreline areas adjacent to natal deltas are especially important to this life history strategy. One reason why adjacent areas may be most important are because of the limited swimming ability of these small fish. Here, we define *adjacent* as being within 5 miles of the edge of delta, although we recognize that physical processes are what likely regulate dispersal of fry.

Recent studies in Whidbey Basin suggest that a major distinguishing feature of habitat use by migrant fry is their use of pocket estuaries (Beamer et al. ). Fry apparently find and occupy these shoreline features of Puget Sound. It is possible that these non-natal "estuaries" function similarly to the functions of the main delta for delta fry. We hypothesize that if a non-natal pocket estuary contains freshwater input early in the year, this could serve as a region of continuing osmoregulation after fry migrants locate pocket estuaries. We speculate that this could have occurred because impacts to major

deltas have caused these pocket estuaries to be more important than they were historically.

We do not fully understand use of pocket estuaries and how factors such as how distance from natal estuary, size, amount of freshwater input, vegetation patterns and so on affect use within and between these systems. For example, tidal influence within a pocket estuary may be important in defining the small scale habitat use patterns for salmon. Flood tides extend into/near riparian areas allowing the fry migrants to access areas higher in an elevated band along the shoreline that may mean access to more terrestrial insects and detritus materials for feeding. We also do not know if non-natal estuaries have similar functions but we believe it is reasonable to hypothesize that these systems provide similar support to migrant fry. Clearly, such a hypothesis needs further study. Consistent with our hypothesis about dispersal, we hypothesize that the closest pocket estuaries (ie within 5 miles) are especially important for this life history strategy because they are directly occupied by the fish. More distant pocket estuaries may have other functions such as export of organic matter and food which should be considered in their management.

While some fry pass quickly through the estuary, others remain to rear in natal estuaries to rear- the delta fry trajectory. Although we have much to learn about use of natal estuaries by Chinook salmon, it is very clear that natal estuarine habitats are a key part of the ecology of this life history strategy. Loss of natal estuary habitat has undoubtedly affected production of this particular life history strategy. Important information needs include data on movements within and between habitat zones, how, flow regimens, tidal cycles and estuarine geomorphology affect distributional patterns, and effects of habitat quality, quantity, and spatial distribution of habitat varies.

As Chinook fry enter the estuary, they are probably distributed and moved through each system by a combination of tidal and fluvial processes. It is likely that these dispersal patterns are unique to each estuary and depend upon the fundamental form and geomorphology of each system. Understanding dispersal patterns are important since this will affect which parts of the estuary the fish can find and then access.

We know from studies in a broad array of estuarine systems that small (1 or 2 order), blind tidal channels (channels that end) or other non-main channel habitats (e.g., sloughs) distributed throughout the estuary are critical habitats for rearing delta fry (Healey 1980; Congleton et al. 1981; Levy and Northcote 1982; Levings et al. 1986; MacDonald et al. 1987; Shreffler et al. 1990; Miller and Simenstad 1997; M. Rowse NWFSC, personal communication; E. Beamer, SST; personal communication; D. Bottom, NWFSC, personal communication). Optimal habitat conditions for juvenile salmon in estuarine and delta areas appear to be a low gradient and shallow water system containing fine-grained substrates (silts and mud), low salinity, wetland vegetation species, and low wave energy (Shreffler and Thom 1993; Aitken 1998; Simenstad 2000). Use of off channel areas can only at higher tides because at lower tides, the channels are often dry. As the tide ebbs and water drains from these marsh channels, fish must move into habitats and areas that are wetted (Mason 1974; Levings et al. 1986). While such cyclic redistributions of fish must occur in all estuaries, what

constitutes suitable low tide refuge is unknown. Presumably fish access larger sloughs, distributary, and main channels, or temporarily leave the delta and move into Puget Sound before migrating back into the vegetated marshes on the next flooding tide. The availability of suitable refuge habitats and their connectivity to marsh channels may be critical features of estuarine habitats and as important to the fish as the channels themselves and therefore warrants further research.

As discussed previously, growth rates can be high in natal estuaries but that considerable variability exists in growth rates from individual estuaries ( ). As we also noted, food items used by juvenile Chinook are diverse and depend upon fish size and habitat type as well as time of year. Within estuaries, insects that are derived from marsh habitats or possibly transported from upstream and terrestrial locations appear to be especially important diet components ( ). In addition, small crustaceans such as amphipods can be important prey types, especially in lower portions of the deltas ( ). In addition to physicochemical processes, Simenstad (2000) discusses the importance of secondary production processes in supporting juvenile salmon across the landscape, with the primary goal of reaching the largest physical size before entering the ocean environment. This, combined with predation issues, "can be a strong determinant to successful return to spawning" (Simenstad 2000). Some of the processes benefiting juvenile salmon and discussed by Simenstad (2000) include 1) primary production (organic matter availability and physical refuge via vegetation, temporal contributions of detritus, and nutrient cycling); 2) retention and decomposition of organic matter (variability in trapping rates by vegetation species, residence time and decomposition of detritus); 3) juvenile salmon growth and survival (salinity transition zones to accommodate sufficient physiological adaptation, low energy habitats for weak individuals, refuge from fish and birds via habitat structure and turbidity, locations of preferred prey concentrations, and prey trapping via certain hydrological action); and 4) trophic relay linkages such as prey export from habitats and subsequent uptake by organisms in the food chain.

Residence times of fish in individual tidal channel complexes varies both within and between systems (Congleton et al. 1981; Levy and Northcote 1982; Shreffler et al. 1990; Miller and Simenstad 1997). Estimates of residence times in estuaries range from 25 to 90 days (Reimers 1973; Healey 1980; Levings et al. 1986). Healey (1980) estimated that residence time of individual fish in the Naniamo River estuary was about 25 days while Levings et al. (1986) estimated that residence times in the Campbell River estuary were 40-60 days. It is interesting that some fish repeatedly use the same channel despite tidal actions (Levy and Northcote 1982). It is unclear what attributes account for variability in residence times within and between different system.

Parr Migrants. During the late spring, juvenile Chinook of the fingerling or parr migrant strategy eventually migrate downstream to the estuary after rearing and growing in freshwater habitat (fingerlings are also sometimes used to denote parr-Bottom et al. 2001). In the estuary, these migrant parr mix with the delta fry where they are indistinguishable except some internal characteristics such as chemical signatures on the otoliths. In addition to these natal fry, there may be non-natal fish that migrate into deltas and mix with natal fish. We do not know if use of delta habitats by parr and



fry and by natal and non-natal fish varies. We assume without further information that Chinook juveniles of a similar size are present in the estuary at the same time use the same habitats, have similar growth rates, diet and so on, regardless of their origin.

Arrival of parr migrants in the delta begins in late May. Catch data from throughout Puget Sound suggests the peak of fingerling migrant abundance in the estuary is May to mid July although small numbers of parr can be found migrating downstream throughout the summer (D. Seiler, WDFW personal communication). Parr migrants migrate downstream towards deltas as they are smolting (D. Seiler, WDFW personal communication).

Yearling Migrants. Some fish within each Puget Sound population of Chinook salmon appear to rear for a year in freshwater before leaving. The proportion of yearlings varies within and between populations. Because of their extended residence in freshwater, they enter natal estuaries at a large size. Available evidence suggests that estuaries function primarily as a migration route to Puget Sound as yearlings are only in estuaries for a short period ( ). We have a poor understanding of habitat use but in the Snohomish, Chinook yearlings were observed in all habitat types (Fresh, personal communication).

Use of Puget Sound Nearshore Habitats. Eventually, all fry that have been rearing in estuarine/delta habitats leave natal estuaries along with migrating parr and yearlings and move into shoreline areas where they probably mingle with migrant fry. Because of similar size, it is impossible without analyzing otoliths or scales to distinguish these life history strategies in the Puget Sound. We have a limited understanding of what causes juvenile Chinook in delta habitats to eventually leave. Two hypotheses, that are not mutually exclusive, seem plausible. One hypothesis is that residence time and emigration of fry from estuaries is size dependent (Healey 1982) with residence time inversely related to fish size at estuarine entry. There is some speculation that the transition of juvenile Chinook into Puget Sound occurs at a specific size (Duffy 2003). For example, Healey (1980) concluded that fry left the estuary at a size of about 70 mm since he never saw smaller fry than this size in adjacent marine waters. This would suggest that larger fish entering the estuary do not stay as long as the early migrating fry and helps explain why parr and yearlings pass relatively quickly through natal estuaries.

Another hypothesis is that emigration from estuaries is dependent upon delta water temperatures. As flows drop, air temperatures rise, and bottom sediments warm, water temperatures in delta habitats will eventually exceed 17 C, a level that is considered stressful to fish. In the Snohomish Delta in 2003, water temperatures >17 C occurred from July to September (M. Rowse, NWFSC, personal communication); water temperatures > 21 C (near lethal to salmon) were consistently found in blind channel habitats. These warm water temperatures may push fish out of channel habitats and into either deeper refuge areas in larger channels or out of deltas into shoreline areas.

Although we have been studying shoreline use of Puget Sound since the 1970's, our understanding of habitat use in this environment is limited. This lack of understanding is

due to a variety of factors including an inability to determine population of origin, an inability separate life history strategies, separate natal and non-natal fish, and an inability to separate hatchery and wild fish. Further, we have yet to systematically evaluate use of shoreline areas based upon habitat characteristics (e.g., how fish respond to variation in substrate or oceanographic features), although emerging data from the Whidbey Basin will help fill this data gap in the near future.

Chinook salmon abundance in shoreline habitats of Puget Sound typically peaks in June and July (Stober and Salo 1973; Fresh et al. 1979), although some juvenile Chinook can be present in shoreline habitats as late as October (Stober and Salo 1973; Fresh 1979; Fresh et al. in prep, C. Rice, NWFSC, unpublished data). As we noted previously, emerging data from coded wire tag recoveries of hatchery fish suggests that Chinook juveniles move about considerably within Puget Sound and do not simply leave Puget Sound in a directed fashion. We assume that wild Chinook from any population are also dispersing widely such that within any area of Puget sound, a mixture of fish from multiple populations can occur. We do not know if use of exposed and protected shoreline areas fundamentally differs for each life history strategy and for fish from different origins within an area. Studies of juvenile salmon use of Puget Sound suggest that shoreline habitats by juvenile salmon are dependent upon size of the fish (Schreiner 1977; Duffy 2003). Therefore, we assume without further information that Chinook juveniles of a similar size in the same place at the same time use the habitat in the same way, have similar growth rates, diet and so on regardless of their origin.

Available literature suggests that there are some fundamental hypotheses regarding use of nearshore habitat use by juvenile salmon that can be defined. First, the area closest to natal deltas will be important as an area for the fish to transition from delta to shoreline habitats; we have defined this area as within five miles. We propose that this area is important because fish are still likely changing physiologically and so the more brackish areas near deltas would help fish finish the smoltification process. In addition, fish are likely more concentrated within this area and hence more vulnerable.

Second, habitat use by juvenile salmon is dependent upon size of the fish (Schreiner 1977; Healey 1980, 1982; Levy and Northcote 1982; Simenstad et al. 1982; Levings et al. 1986; Duffy 2003; Miller and Sadro 2003). Juvenile salmon are generally distributed along a habitat continuum based upon water depth. In general, the depth of the water occupied by the fish increases as the size of the fish increases. We hypothesize that as fish size increases (either from growth or immigration), the fish occupy an increasing diversity of habitats including spending increasing amounts of time in neritic waters (nearshore surface waters) (Stober and Salo 1973; Fresh et al. 1979). Studies demonstrate that the smallest juvenile salmon will be primarily associated with the shallowest habitat. For example, in the Columbia River estuary, subyearling Chinook occurring in shallow, intertidal habitats were smaller than subyearlings captured in deeper pelagic areas while larger, yearling migrants were more prevalent in deeper channel areas (Bottom et al. 1984; McCabe et al. 1986). Because fish are smaller close to natal deltas, we hypothesize that the bay type landscape class with its shallow, low velocity, fine grain substrate is especially important within this zone.

It is not clear whether habitat shifts occur abruptly (e.g., at a transitional size) or fish simply increase the amount of time they spend in different types of habitat (they are not as constrained to certain habitat types). Duffy (2003) hypothesized an abrupt shift in habitat at certain sizes. Simenstad ( ) suggested a similar kind of shift also occurred for chum salmon juveniles. Conversely, within the Columbia River estuary, data suggests that there is a more gradual shift in habitat use with fish spending less time in shallower areas (but not eliminating use of shallower areas) with an accompanying increase in time spent in deeper areas.

Third, throughout all areas of Puget Sound, we hypothesize that a diversity of habitat types and connectivity between habitats at multiple scales is important. Because there are a diversity of sizes of juvenile Chinook salmon present in Puget sound that use a diversity of habitats, a diversity of habitat types is needed to support these fish. Simenstad (2000) and others (e.g., K. Fresh, NOAA-Fisheries, and B. Graeber, NOAA-TRT) stress that because of broad scale landscape integration, juvenile salmon must have a high degree of connectivity between landscape elements.

Fourth, in shoreline habitats, the diet of juvenile Chinook is also diverse as it is in estuaries (Simenstad et al. 1982; MacDonald et al. 1987) with different types of prey dominating. Because they are larger size, Chinook eat larger prey in neritic waters. As in estuaries, insects are interestingly important as prey. Diet studies suggest a broad array of insects can be eaten including. Factors that may affect which insects are eaten include habitat type, time of year, and fish size. In addition, decapod larvae are important prey for smaller fish in neritic waters with fish becoming increasingly important in diets as fish increase in size (Simenstad et al. 1982; MacDonald et al. 1987; Healey 1991).

Sub-Adult and Adult Use of Puget Sound. Eventually, juvenile Chinook salmon recruit fully to the offshore waters of Puget Sound. Once in these more offshore habitats fish may only be occasionally connected with nearshore areas likely while foraging. In offshore waters, fish continue their migration to oceanic feeding grounds. Information collected on hatchery fish suggest that some hatchery fish can remain for extended periods in Puget Sound (Fresh et al. 1981; Hart and Dell 1986). The tendency for some Chinook salmon to remain as extended residents in Puget Sound is well known by fisherman throughout the region. The ecology of these fish in Puget Sound and the factors that determine which fish remain as residents are unclear. For example, we do not know if particular life history strategies or populations contribute differentially to this strategy. However, we assume that this is not a unique strategy for hatchery fish but instead is followed by wild fish throughout the region. This resident strategy constitutes an alternate life history strategy that is distinct from the migrants that leave Puget Sound for ocean feeding grounds.

One factor that appears to be important to resident salmon is the production of herring and other baitfish which are important prey items of these fish (Fresh et al. 1981). Thus, factors affecting production of herring, which are in part related to nearshore habitat conditions, are likely important to this life history strategy. Similarly,

specific areas such as the San Juan Islands may be more important as feeding and migratory corridors for this alternate strategy.

Clearly, adult Chinook salmon must use nearshore habitats. Because adults must access spawning areas, they must use natal estuaries. While there are anecdotal reports of adult Chinook in shoreline habitats while feeding (e.g., kelp habitats in the Straits), we do not have any systematic research on their habitat use in nearshore areas.

Depending upon the population and spawning location, adult Chinook salmon can enter Puget Sound streams to spawn in the spring (spring run fish), summer (summer run fish) or in the fall (fall run fish). Within Puget Sound, the majority of fish enter natal rivers in the fall. Within the Lake Washington and Green River systems, fish have been reported in the estuary as early as June and as late as early October. In Lake Washington, for example, the peak of estuarine entry of fall Chinook salmon is usually in August. Clearly, there can be variability within and between watersheds.

Although we know little about habitat use by adult Chinook within estuaries, one feature of estuarine habitat that appears to be especially important to the adults entering freshwater is water temperature and dissolved oxygen levels. On a large scale, variability in water temperatures can affect variability in emergence timing between populations while annual variability can affect within watersheds. Of concern is the potential for water temperatures with accompanying low dissolved oxygen to delay or even kill adults. Within the Duwamish estuary, several incidences of adult Chinook salmon mortality have been reported that are likely due to low dissolved oxygen levels. Sublethal levels can affect gametes. Delay can be significant as well and cause fish to arrive on spawning grounds at sub-optimal times and increase mortality due to such factors as predation by marine mammals in the estuary.

### Chum Salmon.

Although chum salmon populations are distributed throughout Puget Sound, only the summer spawning type within Hood Canal and the Strait of Juan de Fuca has been listed under the Endangered Species Act. Summer chum return to spawn in late summer or early fall, primarily as three year or four year old fish. There is a distinct odd-even year pattern in returns of chum salmon that matches the odd-even year cycle in pinks is matched by an odd even year cycle in abundance of returning adult chum salmon (Gallagher 1979). The cyclic returns in chum salmon are hypothesized to occur because of competition between pink and chum salmon fry during early marine life (Gallagher 1979, Beachum 1993).

There has been considerable research on chum salmon in Hood Canal but very limited work on populations spawning in the Strait of Juan de Fuca (e.g., Salo et al. 1980; Simenstad et al. 1980; Bax 1983). Inferring use of habitats in Hood Canal based upon this work is problematic for several reasons. First, much of previous research began after we would expect summer chum to enter nearshore waters. Second, work in Hood Canal did not differentiate nearshore use of juvenile chum based upon race

(summer vs. fall chum). While it seems reasonable to assume that the earliest migrants are summer chum, it is not clear where the line between summer chum and normal timed chum occurs. While both races rely on nearshore ecosystems, it is also unclear how such attributes as prey selection, residence time, habitat use and so on may vary between the two groups. We assume that other than obvious differences such as timing of entry into nearshore habitats, that normal timed juvenile chum are a reasonable model for juvenile summer chum. Third, large numbers of hatchery fish have been released into Hood Canal. In general, it has not been possible to discriminate hatchery and wild chum in Hood Canal so some of our knowledge of wild chum behavior has come from hatchery fish. We assume that hatchery chum are a reasonable model for wild chum.

Entry into Natal Estuaries. Summer chum spawn in late summer and early fall in nine watersheds. Fish emerge from the gravel beginning in December in some years. For all practical purposes, there is no rearing in freshwater with fry migrating directly downstream to natal estuaries, often within hours of emergence. Thus, fry arriving in natal estuaries are the same size as emerging fry or <40mm. Genetic (e.g., population of origin, when fish spawn), environmental (e.g., water temperatures), and attributes of each watershed such as hydrology, gradient, temperature regimes, basin size and so on can affect emergence timing and hence timing of estuarine entry. In general, earlier spawning and warmer water temperatures will result in fish arriving in natal estuaries earlier. One implication is that climate changes or watershed scale changes such as riparian forest cover removal that result in warmer water temperatures can result in earlier emergence timing.

Use of Natal Estuaries. One major information need for summer chum salmon is use of natal estuaries as we are unaware of published work on use of these systems by summer chum salmon fry. Based upon studies in Hood Canal, it is clear that many chum fry pass directly through natal estuaries and enter shoreline habitats. This is suggested by the fact that the size of many chum found in littoral zones is the same as that of newly emerged fry (Stober and Salo 1973; Dunford 1975; Healey 1979; Salo et al. 1980; Levy and Northcote 1982; Simenstad et al. 1982). The similarity in size between newly emerged fry and fry found in Puget Sound suggests that chum fry are able to rapidly adapt to seawater (Salo 1991).

Some studies have found larger chum salmon fry in estuaries than newly emerged fry. This suggests that either some limited rearing in natal estuaries is occurring or non-natal fish are entering estuaries from Puget Sound (Healey 1979; Levy and Northcote 1982). Both processes may be occurring. Bax (1983) found that >25% of hatchery releases north of the Skokomish River moved back onto the delta and remained there four days after release. This suggests that fish may occupy non-natal delta habitats. In 2003 in the Snohomish delta, 65mm FL chum fry were found in blind channel networks; although this suggests rearing it is possible they were non-natal fish outside the system (M. Rowse, NWFSC, unpublished data). Studies in Netarts Bay by Percy et al. (1989) and the Nanaimo River estuary by Healey (1979) indicate that residence time of chum salmon juveniles in estuary habitats is inversely related to the size of the fish at



estuarine entry; this is the same model that Chinook appear to follow. Simenstad et al. (1982) suggested that residence time of chum fry in deltas was less than 2 weeks.

It seems plausible to assume therefore that there can be a limited period of delta residence that is no more than two weeks. The proportion of any population rearing probably depends upon both annual and long term variability in environmental and watershed conditions. One plausible hypothesis that could explain extended rearing by juvenile chum salmon is that the occurrence of rearing in a natal estuary by natal fry may depend upon timing and extent of freshwater outflow and structural features of the estuary. Lower flows may "retain" more fry in natal estuaries and allow them to rear. Conversely, higher flows may move more fish out into the Canal. Clearly, freshwater outflow can also affect habitat use within natal estuaries while tidal channel networks may provide low velocity refuges that retain fish.

Because use of habitats in estuaries by Chinook fry and chum fry appear to be similar, it is reasonable to suggest that similar factors may be affecting residence time, habitat use and so on of the two species. While in deltas, chum salmon juveniles appear to use the same types of shallow vegetated channel networks that Chinook use (e.g., Levy and Northcote 1982). This suggests that the availability of low tide refuges and access to these places is critical for chum salmon fry as well as Chinook fry. Levy and Northcote (1982) found chum salmon juveniles used the same tidal channel network for several days. As with juvenile Chinook, we do not know how chum use the various habitat zones within the estuary- e.g., do they move around between zones or do they have to use these habitats in sequence. As with Chinook, growth in estuaries varies both between and within estuary systems (Pearcy et al 1989; Healey 1979, 1982; Table 5); again, as with juvenile Chinook salmon, factors affecting growth are poorly understood.

Dispersion into Hood Canal and Strait of Juan de Fuca. Chum fry eventually enter Hood Canal. We hypothesize that freshwater outflow and water circulation patterns within deltas and the receiving environment (ie Hood Canal) affects initial dispersion of fish into Hood Canal. Large floods and freshets could potentially move fish out with the freshwater plume and a significant distance from natal deltas. Potentially, high flows could even transport fish across the Canal. Structural refuges such as tidal channels may help retain fish within natal estuaries. Fish size may also have an effect on dispersion. Newly emerged fry because of limited swimming ability may be more likely to be transported than larger fry which may have some ability to control their dispersion.

Migration through Hood Canal. Once juvenile summer chum have left natal deltas, they begin their migration to oceanic feeding grounds. As with other species of salmon, migration is not necessarily linear and directed from the Canal. For example, finding chum fry moving south after being released is evidence that fish may have more complex migration patterns than a simple linear movement from Hood Canal (Bax 1983).

Here, we have largely adopted Simenstad's (Appendix Report 3.5, Summer Chum Salmon Conservation Initiative) model of chum fry migration in Hood Canal. This model

suggests that there are two modes of migration directly correlated with fish size. The first mode is for small fry (< 50-55 mm) and proposes that these fish are closely associated with shallow water <2 m deep along the shoreline. This mode is primarily associated with feeding on epibenthic prey resources (e.g., harpacticoid copepods) that are associated with bottom substrates and eelgrass. As a result, the distribution and landscape configuration of eelgrass may have an important influence on performance of chum salmon fry. For example, highly connected eelgrass may enhance chum salmon performance and a loss of connectivity of this eelgrass due to fragmentation by shoreline development may have a direct affect on chum performance. One uncertainty about the functions of eelgrass for the small summer chum salmon is that eelgrass density is at a seasonal low because of winter conditions.

The second mode of behavior applies to fry > 60 mm FL. At a size of approximately 50-60 mm FL, chum begin to make increasing use of neritic or nearshore surface waters. While they do not avoid shallow water, it appears that the range of habitats used by chum fry expands at this size to include these offshore habitats. One hypothesis is that growth rates of chum fry may be optimized at this size by a shift in habitat from shallow water to neritic habitats. Studies of chum salmon throughout their range (Salo 1991) have consistently shown that small chum eat small epibenthic invertebrates while large chum eat mostly pelagic copepods diets (e.g., Healey 1982; Simenstad et al. 1982; Healey 1979; Sibert et al. 1979; Wissmar and Simenstad 1985 year).. The epibenthic prey in shallow water areas are small and often extremely abundant ( ). These types of prey are also supported by detritus based food webs where the organic matter originates from nearshore sources of carbon. This type of prey may provide a bioenergetically rich prey source for small fish but the small size of this prey may be less optimal for larger chum.

One uncertainty in any migration model of chum in Hood Canal that requires future research is the role of non-natal estuarine systems, including pocket estuary systems that chum can encounter along their migration route. There is an extensive system of these estuary systems in the Canal. One possibility based upon recent work by R. Hiroshi (personal communication) is that fish may exploit some of these non-natal estuarine habitats along their migration. Mason (1974), however, reported extensive use of a small delta in British Columbia by chum fry that may have originated from outside the delta since no spawning was reported in the system during the duration of his study. Such use of these systems would suggest that connectivity of these non-natal systems by eelgrass might represent an optimum habitat architecture for summer chum salmon in Hood Canal. If this model is correct, then protection and restoration of summer chum habitat in Puget sound could adopt this strategic approach.

Migration rates of chum salmon along Hood Canal average between 4 and 14 km per day and generally decrease as the season progresses. These rates were developed primarily for normal timed chum so it is not clear whether migration rates are faster or slower earlier in the year. Two hypotheses have been proposed to explain migration rates between and within years. One hypothesis is that migration rate is a function of surface outflow which is determined by strength and duration of wind from the south (Bax 1983). The second hypothesis is that migration rate is a function of foraging

success (Simenstad et al. 1980). This hypothesis suggests that as prey resources increase and foraging success increase, fish migration decreases. Both mechanisms may in fact be true and may operate simultaneously.

Migration rate, especially for the smaller sizes of chum, may be an important performance measure for summer chum because it may relate directly to foraging, growth rate and in turn survival. Because of their small size, factors that increase growth rates should translate directly into larger fish which would increase survival rates for the chum salmon. Thus, abundant prey could slow migration rates which would result in larger fish. In addition, because marine survival rates are directly correlated with size of ocean entry, factors that produce larger fish leaving Hood Canal may be important. Thus, slower migration rates which produce larger fish may enhance survival. While this seems to be a reasonable hypothesis, it is not clear if differences of several days or a week in exiting Hood Canal are significant.

Further, it is not clear if neritic and epibenthic prey communities respond similarly to the same controlling factors in Hood Canal. Although we cannot directly manipulate any sort of wind mediated migration rate, we can potentially affect migration rate, foraging success, and growth rates by the site and landscape scale habitat conditions present in Hood Canal in shoreline areas. For example, as we have noted, the architecture of habitat in shoreline areas may be key to the early life history. It is probable that these same actions would not have the same affect on neritic types of prey. Enhancing growth during the initial stages in Hood Canal may present the best opportunity for recovery actions in the nearshore.

The importance of ecological interactions to summer chum survival is unclear. While the importance of food web processes is obvious, it is not clear whether competition is important to chum. On the one hand chum are one of the few species present in abundance early in the year. Pinks are present at the same time and may be competitors especially in neritic waters where neritic prey are used by both species. The correlations between pink production and chum and Chinook production suggests that some interaction between species may be occurring. It is not clear the nature of this interaction if it is real. Predator populations are presumably low at this time of year as yearling salmonids have not entered Puget Sound in large numbers. Further, bird foraging in winter is limited.

Sub Adult and Adult Use of Nearshore Habitats. Once chum exit Hood Canal we have no information on their habitat use. We do not know if they are associated with nearshore habitats or and how sub basins to the north function for summer chum. As some chum have been observed in Puget Sound late in the fall (Fresh et al. 1981; Hartt and Dell 1986), chum appear to exhibit a resident strategy similar to Chinook. It is not clear whether this characterizes Hood Canal summer chum.

As with Chinook salmon, adult chum make use of at least estuary habitats. Similar to Chinook, they are entering estuaries at times of year when flows are low, potentially affecting access. In addition, seasonal temperatures are also expected to be

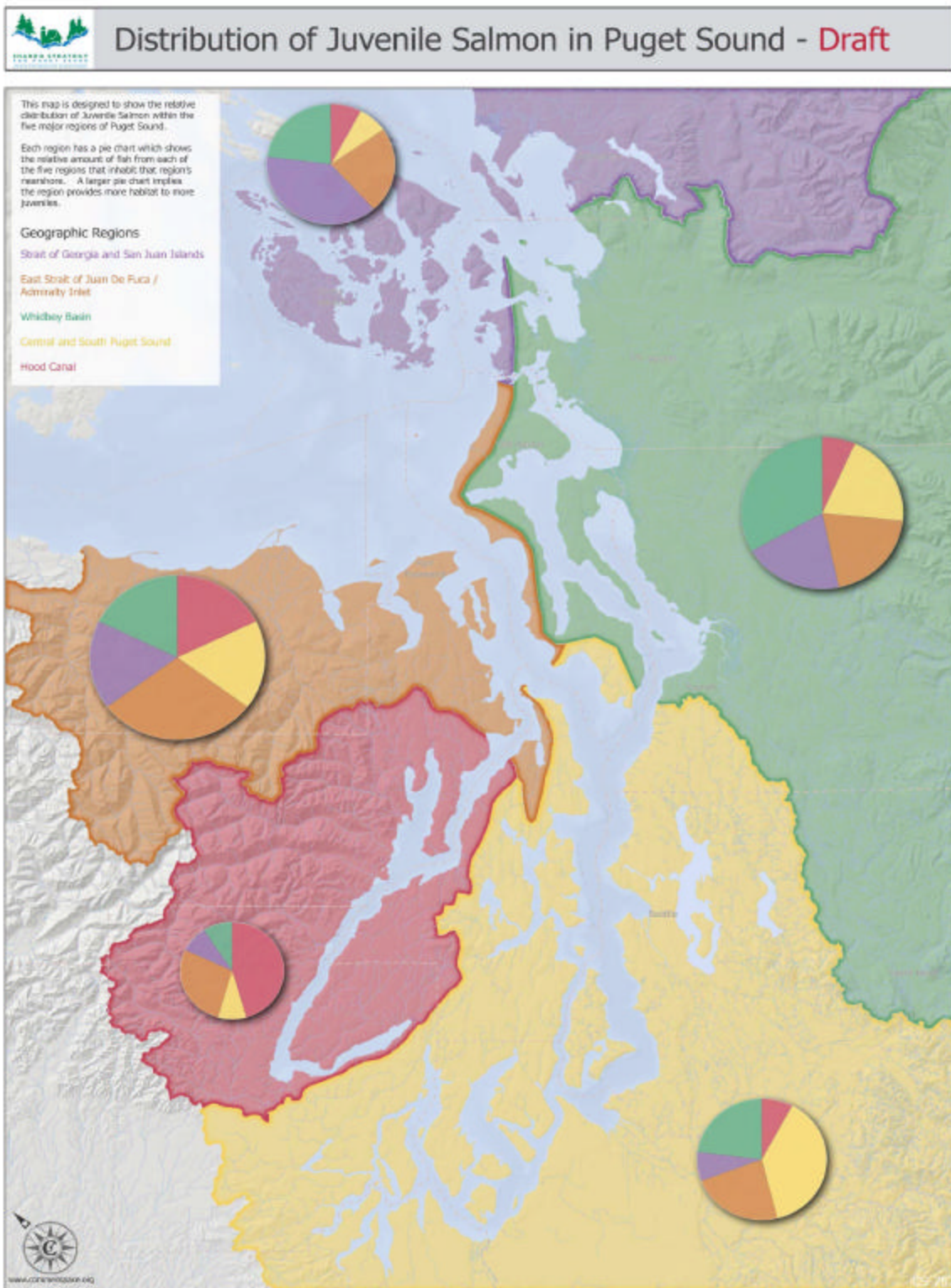
greatest at this time of year which may also affect accessibility and subsequent survival in freshwater of adult summer chum.

#### **f) Geographic Distribution- Differences Between Subbasins**

Research conducted in the last several years in Puget Sound using recovery of coded wire tags (CWT) from hatchery fish has found that juvenile hatchery Chinook salmon disperse widely throughout Puget Sound after passage through natal deltas. For example, Fresh et al. (2003) found CWT hatchery produced juvenile Chinook from 13 different release locations in Sinclair Inlet, a small bay with no natal Chinook populations. Nearly one-third of the CWT hatchery fish recovered in deep South Sound originated from outside of South Sound. Additional research has revealed similar results. For example, a study by Brennan and Higgins (2003) in nearshore waters of central Puget Sound observed and captured juvenile Chinook salmon from 22 different hatcheries and 13 WRIA's (2004 Pacific Estuarine Research Society (PERS) conference abstract); and CWT recoveries in the San Juan Islands from adult salmon between 1978 and 2001 revealed fish from many different populations, including adult Chinook salmon from the Upper, Central and Lower Columbia River, the Snake River in Idaho and Chinook salmon from throughout Puget Sound (data from the Pacific States Marine Fisheries Commission, RMIS database). Thus, at least for hatchery fish, each region of Puget Sound supports both natal and non-natal populations (Figure 4).

Salmon biologists believe it is reasonable to assume that naturally produced fish exhibit similar types of dispersal patterns (K. Fresh, NOAA Fisheries) and that each region of Puget Sound supports both natal and non-natal populations. The degree of support provided by any one region for different populations is unknown, although continuing analyses of CWT Chinook salmon juveniles will provide additional insight in the near future. Based upon personal communications with investigators doing this work in Puget Sound, we propose the following hypotheses about non-natal use of Puget Sound:

1. Areas immediately adjacent to natal estuaries are especially important to natal populations, although they can be also used by non-natal fish,
2. Major estuaries are used by non-natal populations,
3. Regions south of entry points of populations into Puget Sound are less important than areas to the north, and
4. Importance of areas to the south of entry points of populations into Puget Sound decrease with distance.



**Figure 4.** Draft distribution of CWT-recovered Chinook salmon juveniles in Puget Sound.



### **g) Response of Salmon to Nearshore Habitat Conditions**

The endpoint of the conceptual model is the response of salmon to nearshore ecosystem conditions. The response of the salmon is a cumulative result of all the habitat conditions experienced by salmon during their transit through nearshore ecosystems. This response clearly depends upon where the fish have come from (e.g., population and life history strategy) and then where they go after they leave nearshore habitats. What happens to the fish during occupation of nearshore habitats can have an important influence on performance in later life stages. Here, we consider the response of salmon to habitat conditions at three scales: individual fish, populations, and ESU (Figure XXX). Although the primary concern is status or response of the ESU, we propose that it is necessary to consider how individuals and populations respond to understand ESU response.

#### **Response of Individual Salmon to Nearshore Habitat.**

As we discussed previously, habitat consists of attributes or features that can be classified based upon how they affect the opportunity for individual salmon to use that habitat and the capacity of that habitat to support salmon (Figure XXX). The product of capacity and opportunity affects the value of the habitat to individual salmon. Although there are a number of ways to measure performance, value of nearshore habitat to individual salmon is mostly directly measured as survival of individuals. Survival ultimately defines what fish will be successful and contribute to succeeding generations. Nearshore habitats can affect survival in two ways. First, mortality can occur during passage through nearshore ecosystems. Second, it can affect survival potential later in life. For example, the size and timing of fish exiting Puget Sound can affect survival in later stages during ocean residence.

As illustrated by our conceptual model, the ability of nearshore habitats to promote survival not only depends upon the habitat but upon characteristics of the fish themselves including their species, population of origin, and life history strategy. Ideally, survival could be directly measured or indirectly measured through measuring opportunity and capacity which are directly linked to condition of the habitat. This type of analysis is not possible at this time.

#### **Response of Populations.**

Conceptually, nearshore habitats, like all habitats used by salmon during their life, contribute to the viability of salmon populations. NOAA Fisheries (McElhany et al. 2000) defined a viable population as one that has a negligible risk of extinction over a 100 year time period. Thus, changes in viability are used to evaluate effects of recovery actions. Four performance criteria (Viable Salmonid Population or VSP criteria) are used to define viability (McElhany et al. 2000): abundance, productivity, spatial structure, and diversity. All four VSP criteria are critical to the viability of salmon populations, all are interrelated, and levels of all four attributes in aggregate define extinction risk or the likely persistence of the population or ESU.

Briefly, *abundance* is a measure of the number of members in the population (e.g., numbers of spawners or returning adults), while *productivity* is the rate of growth of the population over a given time interval. Productivity can also be expressed as life-stage specific survivals, since the cumulative effects of those survivals results in a population's growth rate over time. Evidence clearly suggests that estuarine habitats contribute to the abundance and productivity of salmon populations (MacDonald et al. 1988; Reimers 1973; Magnusson and Hilborn 2003). *Spatial structure* refers to the geographic distribution of individuals in the population and the processes that generate that distribution. Salmon populations clearly exhibit complex geographic structure that can be defined at multiple spatial scales (e.g., within a natal estuary and between sub-basins). *Diversity* consists of the variability in life history and discrete genetic traits exhibited by members of a population. Diversity in salmon life histories exists along a continuum and includes individuals, subpopulations, populations, ESUs, and species. Spatial structure and diversity are closely related. A major factor affecting the number and quality of life history strategies (quality is defined as how successful the trajectory is at producing recruits) present within a population will be the distribution and quality of habitats that can potentially be used (NRC 1996). In order for a population to use diverse habitats requires that the habitats be available (spatial structure) and that the right fish must be available to use these habitats (e.g., life history strategy).

Populations that have a lot of members and a positive population growth rate are more likely to persist than populations that do not have these characteristics. Distributing members of a population through an array of habitats at multiple scales also helps reduce the vulnerability of the population to shifts in environmental conditions (McElhany et al., Hilborn et al. 2003). Along with spatial structure, having high phenotypic diversity (e.g., lots of members using each life history strategy) helps buffer populations from environmental variability (Taylor 1990, Hilborn et al. 2003).

Nearshore habitats affect population viability by helping to determine which individuals within the population spawn and therefore contribute to succeeding generations. The processes that determine adult survivors occur in all life stages, are biological and non-biological, and operate at multiple scales of space and time.

The ability of each individual to survive is in part affected by the distribution, quality, and amount of nearshore habitats available to that individual. Individuals within a population can be aggregated into different life history strategies. The success of each life history strategy will depend upon the success of individuals associated with that life history strategy which in turn depends upon the availability of appropriate habitats (for that strategy), the landscape context of that habitat (e.g., order habitats are available), the accessibility and quality of that habitat. If the habitats do not exist because of either natural or anthropogenic factors, then population members cannot use them and the number of members using distinct life history strategies can potentially be reduced or ultimately eliminated from the population. Conversely, even if nearshore habitats are available, the appropriate life history strategies must be available to use these habitats. For example, if complex natal estuary habitat is available for the delta fry strategy, the freshwater habitats must be successful at producing the fry to use these habitats.

Fundamentally, the intent of any action is to produce more spawning individuals (increase abundance) of one or more populations. Historically, the focus of salmon management was on maximizing the increase in abundance of individuals (Fresh et al. in press). Each action, however, can be defined more specifically in terms of how it affects viability of a particular population (in essence how it creates more salmon) depending upon the circumstances of that action (e.g., whether it affects habitat opportunity or capacity). For example, from the perspective of the Snoqualamie Chinook salmon population, actions taken in South Puget Sound (south of the narrows) will primarily affect spatial structure and diversity of the population because it will not substantially change abundance or productivity levels. Actions taken in the Snohomish Estuary that affect the rearing capacity of delta fry will change the composition of life history strategies. Because it increases the number of members of the dominant life history strategy, abundance and productivity levels can be affected. Actions that increase abundance levels of non-dominant life history strategies primarily affect life history diversity and spatial structure because they have a relatively small affect on overall population abundance, at least over the short term.

#### RULES FOR HOW VIABILITY CAN BE AFFECTED BY DIFFERENT ACTIONS (IN PROGRESS) (NOT SURE IS DOABLE)

Each life history strategy will contribute differentially to the population based upon the cumulative affect of all natural and anthropogenic factors affecting the habitat. The success in aggregate of all the life history strategies over long time scales then determines the viability of that population. For example, if all life history strategies within a population are highly productive, population viability can be high while if only one strategy is successful, viability will tend to be lower and the population will be more at risk to extinction events in the future. Over long time and short scales, conditions will change that will affect the success of each strategy. As a result, strategies that have low productivity during a particular time period may become more productive as large scale environmental changes occur.

#### Response of ESU's.

ESU's are composed of populations. Thus, it is the aggregate response of all the populations within an ESU that will determine whether or not there is a change in viability of an ESU. There is not a correct or single mix of populations associated viability within an ESU that will determine status of the ESU. Conceptually, the viability of enough populations within an ESU has to increase for ESU viability to increase.